JEPonline

Journal of Exercise Physiologyonline

Official Journal of The American Society of Exercise Physiologists (ASEP)

ISSN 1097-9751
An International Electronic Journal
Volume 4 Number 4 November 2001

Body Composition

ASEP METHODS RECOMMENDATION: BODY COMPOSITION ASSESSMENT

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ABSTRACT

VIVIAN HEYWARD. **ASEP Methods Recommendation: Body Composition Assessment**. JEP**online**. 2001;4(4):1-12. This paper provides an overview of laboratory and field methods commonly used in research, clinical, and health/fitness settings to obtain valid measures of body composition and recommends specific methods and prediction equations for this purpose. These recommendations reflect the current state of knowledge about body composition assessment but are subject to modification as new information and technology become available. An extensive review of the literature suggests that densitometry (hydrodensitometry and air displacement plethysmography), hydrometry, and dual-energy x-ray absorptiometry are commonly used to obtain reference measures of body composition in research settings. Typically, estimates of body composition from densitometry or hydrometry are obtained using two-component body composition models (Body mass = fat-free mass + fat mass). The limitations of two-component models are addressed. Also, the merits, shortcomings, and technical errors associated with each of these laboratory methods are compared. Given that each of these reference methods yields indirect measures of body composition, none can be singled out as the "gold standard" method for *in vivo* body composition assessment. It is recommended, instead, that variables obtained from all three methods be used with a multi-component, molecular model to derive reference measures of body composition for research dealing with the development and validation of field methods and prediction equations. Bioelectrical impedance analysis, skinfolds, and other anthropometric methods are widely used in health/fitness settings to assess body composition. The predictive accuracy of these field methods and prediction equations is limited by the absence of a single "gold standard" reference method. An overwhelming majority of field method prediction equations have been developed and cross-validated using a two-component, molecular body composition model in conjunction with only one reference method. Therefore, the prediction error for the body composition estimates obtained with these equations may be greater than expected especially if the individual's fat-free body density differs greatly from the value assumed for two-component models. With this caution, recommendations are made regarding selected methods/equations to use with diverse subgroups of the population.

Key Words: hydrodensitometry, air displacement plethsymography, dual-energy x-ray absorptiometry, bioelectrical impedance, skinfolds, anthropometry, body composition models, validity of body composition methods

INTRODUCTION

In laboratory and clinical settings, exercise scientists routinely assess body composition to identify individuals at risk due to excessively low or high levels of total body fat. In addition, exercise physiologists can use body composition measures in a number of ways. Monitoring changes in fat-free mass (FFM) and fat mass (FM) can further our understanding of energy metabolism and disease processes, leading to the development of more effective nutrition and exercise intervention strategies to counteract the loss of FFM associated with factors such as malnutrition, aging, injury, and certain diseases. Body composition data can also be used to estimate healthy body weights for clients and to determine competitive body weights for athletes, especially for those participating in sports that use body weight classifications for competition. Furthermore, exercise physiologists can monitor growth, maturation, and age-related changes in body composition.

Theoretical models are used to obtain reference or criterion measures of body composition. To study body composition, the body mass is subdivided into two or more compartments using atomic, molecular, cellular or tissue models (1). Over the past 60 years, two-component molecular level models, developed by Brozek et al. (2) and Siri, (3), have been widely used to acquire reference measures of body composition and to validate body composition field methods and prediction equations. The classic two-component model divides the body mass into fat and fat-free body (FFB) compartments. The fat mass (FM) consists of all extractable lipids from adipose and other tissues; the FFB includes water, protein, and mineral components (3). The Siri two-component model assumes that (a) the densities of fat (.901 g/cc) and the FFB (1.10 g/cc) are similar for all individuals, (b) the densities and relative proportions of water, protein, and mineral components in the FFB are constant for all individuals, and (c) the individual differs from the "reference" body only in the amount of fat. Using these assumed proportions and their respective densities, Siri developed a conversion formula to estimate relative body fat (% BF) from total body density (Db): $\%BF = [(4.95/Db) – 4.50] \times 100$. The Brozek et al. (2) two-component model conversion formula is based on a reference body with a specified total Db and assumes slightly different values for the density of fat (0.88876 g/cc) and the FFB (1.10333 g/cc): $\%BF = [(4.57/Db) – 4.142] \times 100$. These two conversion formulas yield similar %BF estimates (within 0.5 to 1.0 %BF) for total Dbs ranging from 1.0300 to 1.0900 g/cc.

Body Composition Reference Methods: Is there a "Gold Standard" Method?

There are a number of highly sophisticated, but expensive, methods that may be used to obtain reference measures of body composition, including computerized tomography, magnetic resonance imagery, and neutron activation analysis. Alternatively, densitometry, hydrometry, and dual-energy x-ray absorptiometry are more commonly used in research settings to obtain reference measures of body composition. All of these methods are subject to measurement error and have basic assumptions that do not always hold true. Therefore, none can be considered singly as a "gold standard" for *in vivo* body composition assessment.

Densitometry

Densitometry refers to the measurement of total Db and the estimation of body composition from Db. Db is the ratio of body mass to body volume (BV); BV is measured by either water displacement or air displacement. For years, a water displacement method, known as hydrodensitometry or hydrostatic weighing, has been considered by some experts as a gold standard method in light of the relatively small technical error associated with the accurate measurement of Db (0.0015 g/cc or approximately 0.7% BF) (Figure 1). In order to achieve this degree of accuracy, total body mass, underwater weight, water temperature, and residual lung volume (RV) must be measured precisely (within 0.20 kg for body mass and underwater weight, within 0.0005 degrees

Figure 1: A client submerged in water during the measurement of underwater weight using a load cell platform system.

Celcius (°C). for water temperature, and within 100 ml for RV). The estimated technical error associated with the RV measurement (0.00139 g/cc) is relatively large compared to the other three sources of error combined (0.0006 g/cc) (4).

Figure 2: Measurement of residual volume.

For research purposes, RV should be measured, not predicted (Figure 2). RV prediction equations typically have standard errors of estimate in excess of 500 ml (5). RV can be measured using closed-circuit helium, nitrogen, or oxygen dilution methods or an open-circuit nitrogen washout method (4). Although there is good agreement between measurements of RV on land and in the water, preferably RV should be measured in the tank simultaneously with the underwater weight instead of outside of tank prior to the underwater weighing. Simultaneous measurement of RV in the tank yields more valid estimates of Db and is less time-consuming and easier for the client to perform (4).

Hydrostatic weighing requires considerable subject cooperation given that multiple trials need to be performed in order to obtain an accurate estimate of underwater weight. Although some researchers have established selection criteria based on 10 underwater weighing trials (6,7), generally, most clients will achieve a stable underwater weight in 4 to 5 trials. Bonge and Donnelly (8) recommend using the average of three trials within 100 g to represent the underwater weight of the client. This method may be more suitable, especially for clients who do not have the ability to perform 10 trials.

Figure 3: A client in a Bod Pod™, being measured for body density by air displacement plethysmography.

Elderly people, children, physically challenged persons, individuals with certain diseases may not be able to comply with standardized hydrostatic weighing procedures. As an alternative, body volume and Db can be measured by air displacement plethysmography (Figure 3). Research demonstrates that the Bod Pod ™, an air displacement plethysmograph, provides reliable and valid estimates of Db and %BF compared to hydrostatic weighing in adults (9). The within-day test-retest reliability of the Bod Pod™ was slightly better than that of hydrodensitiometry (CV = 1.7% and 2.3% for Bod Pod™ and hyrdrodenitometry, resepectively). On average there was a 0.3% BF difference between body fat estimates from these two methods. However, recent studies reported that the Bod Pod systematically overestimated the average %BF (by approximately 2%BF on average) of Black men (10) and underestimated the average %BF (by approximately 2%BF) of Division I collegiate football players (11). Thus, at the present time, it may be premature to recommend replacing hydrodensitometry with air displacement plethysmography when assessing Db in research settings. Additional research documenting the validity of this device for individuals from diverse groups of the population is warranted.

Regardless of the method used to measure total Db, a potential source of measurement error for both these methods is the conversion formula used to estimate % BF from Db. Research demonstrates that the assumptions underlying the use of the classic two-component models, developed by Siri and Brozek et al., may not be met in many groups of individuals. For example, the FFB density can vary from the assumed value (1.10 g/cc) due to age, gender, level of body fatness, physical activity, and ethnicity (12-14). Moreover, these models are not appropriate to assess the body composition of individuals with diseases that alter the relative proportions of water (e.g., malnutrition and obesity, protein (e.g. AIDS and cancer), and mineral (e.g., osteoporosis) in the FFB. Although densitometric methods yield an accurate measure of Db, Lohman (13) speculated that variability in FFB composition could lead to a 2.8% BF error when estimating relative body fat from Db in a homogenous population (similar in age, gender, and ethnicity). In light of this limitation, neither hydrodensitometry nor air displacement plethysmography can be considered as a "gold standard" method for assessing body composition.

Hydrometry

Hydrometry, or the measurement of total body water (TBW), is also limited when used singly to derive reference measures of body composition. With this method, the concentration of hydrogen isotopes (deuterium or tritium) in biological fluids (saliva, plasma, and urine) after equilibration is measured and used to estimate TBW (15). This method assumes that the distribution and exchange of the isotope by the body are similar to the distribution and exchange of water. However, due to the exchange of the isotope with nonaqueous hydrogen in the body, TBW may be overestimated by 1 to 5% (16). Using this method in conjunction with the two-component molecular model to obtain estimates of FFM, it is further assumed that the hydration of the FFM is constant for all individuals (~ 73% of FFM). Because TBW fluctuates widely within and among individuals depending on age, gender, level of obesity, and disease, large errors may result when hydrometry is used with the two-component model to derive reference measures of body composition. Siri (3) estimated that biological variability (2%) in the hydration of the FFB would produce a substantial error in the estimation of body fat (2.7% BF) for the general population.

Dual-energy X-ray Absorptiometry

Dual-energy x-ray absorptiometry (DXA) is a relatively new technology that is gaining recognition as a reference method for body composition research (Figure 4). This method is based on three-compartment model that divides the body into total-body mineral, mineral-free lean, and fat tissue masses. The precision of DXA in measuring %BF is estimated to be 1.2%BF (17-19). DXA is highly reliable, and there is good agreement (~0.4 %BF difference) between %BF estimates obtained by hydrodensitometry (Db adjusted for relative total-body mineral and TBW) and DXA (20-22). In addition to obtaining estimates of relative body fat and lean tissue mass, DXA provides segmental and regional measures of body composition.

Figure 4: A client being scanned using dual energy x-ray absorptiometry (DXA).

DXA is an attractive alternative to hydrodensitometry as a reference method because it is rapid (a total body scan takes 20 minutes), safe, requires minimal subject cooperation, and, most importantly, takes into account interindividual variability in bone mineral content. Also, DXA estimates of body composition appear to be less affected by fluctuations in TBW compared to hydrodensitometry and hydrometry. Kohrt (23) estimated that a 5% difference in the relative hydration of the FFB (78 vs 73% FFB) would produce <0.5 kg error in fat and FFM, suggesting that hydration status has a relatively small effect on soft-tissue estimates obtained via DXA.

However, Lohman (18) pointed out that anteroposterior thickness of the client and variation in fat distribution may affect the accuracy of DXA estimates of soft tissue. Also, standardization of DXA technology is imperative before it can be universally accepted as a reference method for body composition assessment. DXA estimates of fat mass depend on the manufacturer (Hologic vs. Norland vs. Lunar), the data collection mode (pencil beam vs.

array beam), and the software version used to analyze the data (18). Thus, it is somewhat difficult to establish the validity of DXA for body composition assessment in comparison to other reference methods (i.e., hydrodensitometry and multicomponent models). Still, researchers are beginning to use DXA to develop and cross-validate body composition field methods and prediction equations (24-26).

In the future, it is highly likely that additional body composition methods and prediction equations will be developed and validated using DXA as a reference method, especially for population subgroups for whom hydrodensitometry is not feasible (e.g., spinal cord injured and elderly). However, further research and standardization of this technology are needed before DXA can be firmly established as "gold standard" reference method (18,23,27).

Recommendation

Because each of these three reference methods (densitometry, hydrometry, and DXA) yield indirect estimates of body composition, none can be singled out as the "gold standard" for *in vivo* body composition assessment. In fact, many researchers have obtained more valid reference measures of body composition by using variables obtained from all three methods. There are multicomponent molecular model approaches that adjust Db from densitometry for variations in TBW (measured by hydrometry) and total body mineral (measured by DXA estimates of bone mineral). These models (13,28) take into account interindividual variablility in the hydration and/or mineral content of the FFB; therefore, more accurate estimates of body composition may be obtained compared to using any of one of these methods singularly. Thus, for research purposes, it is recommended that all three methods be used in conjunction with a multicomponent model in order to derive valid reference measures of % BF, FM, and FFM.

Body Composition Field Methods

Three methods often used by exercise physiologists to assess body composition of individuals in field and clinical settings are bioelectrical impedance analysis, skinfolds, and anthropometry. Given the choice of methods and numerous prediction equations published in the literature, it is often difficult for the clinician to select an appropriate method or prediction equation that accurately assesses the body composition of each client. Thus, the validity of the body composition field method and the predictive accuracy of equations need to be carefully evaluated. The relative worth of prediction equations is established by researchers by comparing predicted scores to reference measures of body composition. In general, good prediction equations have several characteristics in common: (a) use of acceptable reference methods to obtain criterion measures of body composition, (b) use of large, randomly selected samples (N>100), (c) high correlation between the reference measure and predicted scores ($r_{y,y'} > .80$), (d) small prediction error or standard error of estimate (Table 1), and (e) cross-validation of equation on additional, independent samples from the population.

Table 1. Standards for Evaluating Prediction Errors (SEE)

SEE %BF	*SEE Db (g/cc)*	*SEE FFM (kg)*		*Subjective Rating*
Male and Female	Male and Female	Male	Female	
2.0	0.0045	2.0-2.5	1.5-1.8	Ideal
2.5	0.0055	2.5	1.8	Excellent
3.0	0.0070	3.0	2.3	Very Good
3.5	0.0080	3.5	2.8	Good
4.0	0.0090	4.0	3.2	Fairly Good
4.5	0.0100	4.5	3.6	Fair
5.0	0.0110	>4.5	>4.0	Poor

Data from Lohman (13, pp. 3-4).

The predictive accuracy of field methods and equations is limited by the absence of a single "gold standard" method for obtaining *in vivo* reference measures of body composition. Although densitometry, hydrometry, and dual-energy x-ray absorptiometry are often used as reference methods, these methods provide only an indirect measure of body composition and, therefore, are subject to measurement error. As much as 50% of the prediction error for body composition field method equations can be attributed to errors associated with the reference method. Few studies have used all three of these methods together and multicomponent models to derive reference measures for the development and cross-validation of field method equations. Thus, many equations are limited in that they provide only a two-component model estimate of body composition. To select the most appropriate method and prediction equation factors such as age, gender, physical activity, level of body fatness, and ethnicity need to be taken into consideration. It is important to make certain that these physical characteristics of your client are similar to those of the validation sample used to develop or cross-validate a specific prediction equation.

Bioelectrical Impedance Analysis

Bioelectrical impedance analysis (BIA) is a rapid, noninvasive, and relatively inexpensive method for evaluating body composition in field or clinical settings. With this method, the impedance or opposition to current flow through the entire body is measured with a single-frequency bioimpedance analyzer [e.g., RJL (Detroit, MI); Valhalla Scientific (San Diego, CA); Biodynamics (Seattle, WA)] (Figure 5). The individual's TBW is estimated from impedance measures. The resistance to current flow will be greater in individuals with large amounts of body fat given that adipose tissue is a poor conductor of electrical current due to its relatively low water content. Because the water content of the FFB is relatively large (~73%), FFM can be estimated from TBW. Individuals with a large FFM and TBW have less resistance to current flowing through their bodies compared to those with a smaller FFM. For more detailed information regarding this method, see Kushner (29) and Baumgartner (30).

Figure 5: A client being measured by whole-body bioelectrical impedance (BIA).

Table 2. Selected BIA Prediction Equations

Ethnicity	*Gender*	*% BF Level (Age)*	*Equation*	*Ref.*
American Indian, Black, Hispanic, or White	Men[a]	<20 %BF (17-62 yr)	FFM (kg) = 0.00066360(HT^2) - 0.02117(R) + 0.62854(BW) - 0.12380(AGE) + 9.33285	(31)
		≥20 %BF (17-62 yr)	FFM (kg) = 0.00088580(HT^2) - 0.02999(R) + 0.42688(BW) - 0.07002(AGE) + 14.52435	(31)
American Indian, Black, Hispanic, or White	Women[a]	<30 %BF (17-62 yr)	FFM (kg) = 0.000646 (HT^2) - 0.014 (R) + 0.421 (BW) + 10.4	(31)
		≥30% BF (17-62 yr)	FFM (kg) = 0.00091186 (HT^2) - 0.01466 (R) + 0.29990 (BW) - 0.07012 (Age) + 9.37938	(31)
White	Boys,Girls	8-15 yr	FFM (kg) = 0.62 (HT^2/R) + 0.21 (BW) + 0.10 (Xc) + 4.2	(13)
	Boys,Girls	10-19 yr	FFM (kg) = 0.61 (HT^2/R) + 0.25 (BW) + 1.31	(33)

[a] For clients who are obviously lean use the < 20% BF (men) and <30% BF (women) equations ; For clients who are obviously obese, use the ≥20% BF (men) and ≥30% BF (women) equations ; For clients who are not obviously lean or obese, calculate their FFM using both the lean and obese equations and then average the two FFM estimates (Stolarczyk et al. 32).

Commonly used whole-body BIA equations are presented in Table 2. These equations (31,32) provide two-component model estimates of FFM for men and women from diverse ethnic groups (American Indian, Black, Hispanic, and White). The equations for children (13,33) were based on three-component model estimates of

FFM with Db adjusted for TBW. On average, these equations will accurately estimate FFM within ±2.8 kg for women, ±3.5 kg for men, and ±2.1 kg for children.

Table 3. BIA Client Guidelines

- ***No eating or drinking within 4 hours of the test.***
- ***No exercise within 12 hours of the test.***
- ***Urinate within 30 minutes of the test.***
- ***No alcohol consumption within 48 hours of the test.***
- ***No diuretic medications within 7 days of the test.***
- ***No testing of female clients who perceive they are retaining water during that stage of their menstrual cycle.***

In order to ensure the predictive accuracy of these equations, clients must strictly follow each of the BIA Testing Guidelines (Table 3). In addition, standardized testing procedures must be followed. Although the relative predictive accuracy of the BIA method is similar to that of the skinfold method, BIA may be preferable for the following reasons: (a) the method does not require a high degree of technical skill, (b) the method is more comfortable and less intrusive for the client, and (c) this method can be used to estimate body composition of obese individuals (31).

Recently, less expensive, segmental bioimpedance analyzers have been marketed. The Tanita™ analyzer measures lower-body resistance between the right and left legs as the individual stands on the electrode plates of the analyzer (Figure 6). The OMRON™ analyzer is hand-held (electrode plates are gripped) and measures upper-body impedance between the right and left arms (Figure 7). To date there is limited research addressing the validity and applicability of these methods and their prediction equations for diverse subgroups of the population.

Figure 6: A client being measured via BIA using the Tanita™ analyzer.

Figure 7: A client being measured via BIA using the OMRON™ analyzer.

Skinfold Method

The skinfold (SKF) is an indirect measure of the thickness of subcutaneous adipose tissue at a specified site (Figure 8). Most SKF equations use two or more SKF measurements to predict either Db or %BF. For a detailed description of SKF sites and measurement techniques, see Harrison (34). The accuracy and precision of SKF measurements is highly dependent on technician skill, type of SKF caliper, and client factors. It takes a great deal of time and practice to develop skill as a SKF technician, and standardized procedures must be carefully followed (34). Compared to high-quality metal calipers (e.g. Lange or Harpenden calipers), plastic calipers have less scale precision (~2 mm), non-constant tension throughout the range of measurement, a smaller measurement scale (~40 mm), and less consistency when used by inexperienced SKF technicians (35). Generally, SKFs should not be measured immediately following exercise due to the possible accumulation of extracellular fluid (edema) in the subcutaneous tissue. Also, the SKF method is not recommended for assessing body composition of obese individuals. Oftentimes, an obese individual's SKF thicknesses exceed the maximum aperture of the caliper. Even highly-skilled SKF technicians have difficulty measuring SKF thicknesses of obese clients.

Figure 8: The measurement of the triceps skinfold.

The SKF method may be used to estimate body composition of children (Black and White) and adults (36,37) from diverse ethnic groups (Black, Hispanic, and White), as well as female and male athletes (Table 4). On average, these equations will accurately predict Db within +/- .0080 g/cc and two-component model estimates of %BF within +/-3.5% BF. Whenever possible, use population-specific conversion formulas to convert Dbinto % BF (Table 5). The SKF equations for children directly estimate %BF instead of Db. These equations were developed using a multicomponent body composition model that included measures of Db, TBW, and bone mineral (38).

Table 4. Skinfold Prediction Equations

SKF Sites	*Groups*	*Gender*	*Age**	*Equation*	*Ref.*
S7SKF (C + A + Th + Tr + Sub + Sup + MA)	Black or Hispanic	Women	18-55	Db (g/cc)[a] = 1.0970 - 0.00046971(Σ7SKF) + 0.00000056(Σ7SKF)^2 - 0.00012828(AGE)	(37)
	Black or Athletes	Men	18-61	Db (g/cc)[a] = 1.1120 - 0.00043499(Σ7SKF) + 0.00000055(Σ7SKF)^2 - 0.0002882(AGE)	(36)
S4SKF (Tr + SupA+ A + Th)	Athletes	Women	18-29	Db (g/cc)[a] = 1.096095 - 0.0006952(Σ4SKF) – 0.0000011(Σ4SKF)^2 - 0.0000714(AGE)	(37)
S3SKF (Tr + Sup + Th)	White or Anorexic	Women	18-55	Db (g/cc)[a] = 1.0994921 - 0.0009929(Σ3SKF) + 0.0000023(Σ3SKF)^2 - 0.0001392(AGE)	(37)
(C + A + Th)	White	Men	18-61	Db (g/cc)[a] = 1.109380 - 0.0008267(Σ3SKF) + 0.0000016(Σ3SKF)^2 - 0.0002574(AGE)	(36)
S2SKF (Tr + Ca)	Black or White	Boys	6-17	%BF = 0.735(ΣSKF) + 1.0	(38)
	Black or White	Girls	6-17	%BF = 0.610(ΣSKF) + 5.1	(38)

ΣSKF = sum of skinfolds (mm) ; A=abdomen, C=chest, Ca=calf, MA=midaxilla, Sub=subscapular, Sup=suprailiac, SupA=anterior suprailiac, Th=thigh, Tr=tricep ; *Age in years ; [a] Use population-specific conversion formulas to calculate % BF from Db.

Table 5. Population-Specific Formulas for Conversion of Db to % BF

Population	*Age*	*Gender*	*% BF*	*FFB_d (g/cc)**
Ethnicity				
American Indian	18-60	Female	(4.81) / Db - 4.34	1.108
Black	19-45	Male	(4.86) / Db – 4.39	1.106
	24-79	Female	(4.85) / Db – 4.39	1.106
Hispanic	20-40	Female	(4.87) / Db – 4.41	1.105
Japanese Native	18-48	Male	(4.97) / Db – 4.52	1.099
		Female	(4.76) / Db – 4.28	1.111
	61-78	Male	(4.87) / Db – 4.41	1.105
		Female	(4.95) / Db – 4.50	1.100
White	7-12	Male	(5.30) / Db – 4.89	1.084
		Female	(5.35) / Db – 4.95	1.082
	13-16	Male	(5.07) / Db – 4.64	1.094
		Female	(5.10) / Db – 4.66	1.093
	17-19	Male	(4.99) / Db – 4.55	1.098
		Female	(5.05) / Db – 4.62	1.095
	20-80	Male	(4.95) / Db – 4.50	1.100
		Female	(5.01) / Db – 4.57	1.097
Levels of Body Fatness				
Anorexic	15-30	Female	(5.26) / Db – 4.83	1.087
Obese	17-62	Female	(5.00) / Db – 4.56	1.098

Anthropometry

Anthropometry refers to the measurement of the size and proportions of the human body (Figure 9). Anthropometric prediction equations estimate Db, %BF, or FFM from combinations of body mass, standing height, skeletal diameters, and circumference measures. Compared to SKF measures, these anthropometric techniques are relatively simple, inexpensive, and require less skill and training. The accuracy and precision of anthropometric measures, however, are affected by technician skill and client factors. Technician skill is less of a problem provided that standardized procedures are closely followed for locating measurement sites, positioning the skeletal anthropometer and tape measure, and applying tension during the measurement (39). Variability between technicians is relatively small (0.2 to 1.0 cm) for circumference measures. Although skilled technicians can obtain similar values when measuring the circumferences of obese clients, it is more difficult to obtain consistent measurements for obese compared to lean individuals (40). However, circumferences are preferable to SKFs when measuring obese clients for the following reasons: (a) regardless of size, circumferences of obese individuals can be measured; whereas, the SKF thickness may exceed the maximum aperture of the caliper, and (b) circumferences require less technician skill, and the difference between technicians is smaller compared to SKF measurements (40).

Figure 9: Body circumference measurement

The anthropometric equations presented in Table 6 can be used to predict the Db of females (41) and two-component model estimates of %BF for obese women (42) and men (43). In general, these equations estimate body composition with a fair to good degree of accuracy (~3.0 to 3.6% BF).

Table 6. Anthropometric Prediction Equations

Ethnicity	*Gender*	*Age**	*Equation*	*Ref.*
White	Women	15-79	Db (g/cc)[a]= 1.168297 - 0.002824(Abdom C[b]) + 0.0000122098(Abdom C[b])^2 - 0.000733128(HIP C) + 0.000510477(HT) - 0.000216161(AGE)	(41)
White	Obese Women	20-60	% BF = 0.11077 (Abdom C[b]) - 0.17666 (HT) + 0.14354 (BW) + 51.033	(42)
				(43)
	Obese Men	24-68	% BF = 0.31457 (Abdom C[b]) - 0.10969 (BW) + 10.834	

*Age in years ; [a] Use population-specific conversion formula to calculate % BF from Db ; [b]Abdom C (cm) is the average abdominal circumference measured at two sites: (1) anteriorly midway between the xiphoid process of sternum and the umbilicus and laterally between the lower end of the rib cage and iliac crests and (2) at the umbilicus level.

Recommendations

It is important to recognize that most field methods provide only a two-component model estimate of body composition. In light of this limitation, the following methods are recommended to assess body composition of various population subgroups (see tables for specific equations):

1. The whole-body bioimpedance method may be used to assess the FFM of adults (American Indian, Black, Hispanic and white) and children (Black and white).
2. The skinfold method may be used to assess the Db of nonobese adults (Black, Hispanic, and white) and athletes (male and female), as well as the %BF of children (Black and white).
3. The skinfold method should *not* be used to assess body composition of obviously obese individuals.
4. Anthropometric (circumference) equations may be used to assess the %BF of obviously obese men and women.

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